Highlighting twenty years of salinity research in Spain's Ebro River Basin

R Aragüés, D Isidoro, R Isla, V Urdanoz
CITA-DGA (Agri-food Research and Technological Center of Aragón), Department of Soils and Irrigation (associated to CSIC), Zaragoza, Spain

Introduction

The 85.400 Km^2 Ebro River Basin (ERB) has an irrigated area of 785.000 ha, equivalent to 21% of the total irrigated area in Spain. In the middle ERB, 420.000 ha are irrigated, and about 100.000 ha are salt-affected due to the weathering of tertiary geologic materials high in native salts, coupled to a poor management of soil and water. Salinity has therefore a major impact on the quality of soils and waters and on the productivity of crops grown in the middle ERB. Table 1 highlights some of the salinity studies performed by CITA in the middle ERB on soils, waters and crops. The scientific and technical publications related to these studies as well as additional information on the Department of Soils and Irrigation may be downloaded from www.cita-aragon.es

Table 1 Main salinity studies performed by CITA on soils, waters and crops. Examples for studies in italics are reported in this publication

Soils	Waters	Crops
- Reclamation of salt-affected soils. Use of gypsum by-products - *Diagnosis of soil salinity (invasive/non invasive)* - Water quality-soil's structural stability relationships	- *Quality analysis of ERB waters* - Irrigation return flow (IRF) hydrosalinity models - Hydrosalinity balances (irrigation/hydrological basin levels) - Deficit irrigation and soil salinity	- Development of systems for establishing field salinity gradients (TLS, DIS) - Salinity tolerance of crops under field conditions - *Response of crops to saline sprinkling irrigations. Management strategies*

Although these studies over the last twenty years have improved our understanding of the salinity problems in the ERB, the resources devoted and the scientists involved in these studies have been insufficient for a successful and sustained effort at addressing this problem. The following sections give examples of these studies in the soils, waters and crops research lines.

Soils

Electromagnetic (EM) sensors have been used since the early 80's to delineate soil salinity. A costeffective, mobile, georeferenced EM sensor (MGES) was developed and applied in the 715 ha Barranco de Lerma basin (Bardenas II, Aragón, Spain) for establishing the ECah (apparent soil electrical conductivity measured in the horizontal coil configuration) map (Fig. 1) (Urdanoz et al., 2008). Since ECa is closely related to soil salinity when other soil variables (as water content or texture) are relatively uniform (Rhoades et a., 1999), this ECah map was the basis for relating soil salinity to drainage water salinity (ECdw).

The Barranco de Lerma basin was disaggregated into 25 watersheds (Fig. 1) using a Digital Elevation Model. The surface-weighted ECah* for each watershed was calculated from the ECah intervals shown in Fig. 1 and the corresponding areas for each interval. The areas with ECah < 0.2 dS m^{-1} (i.e., non-saline) were not included in the calculation of ECah*. Water samples were taken after a precipitation event at the drainage exit of each watershed and the EC was measured in the lab (Fig. 1).

A linear regression analysis of ECah* on ECdw was performed for the 25 watersheds in order to ascertain its significance and to identify the main salinity-source areas contributing to salinity in drainage waters. Both variables were significantly correlated ($P < 0.001$) (Fig. 2). Two drainage points located in the vicinity of the irrigation canal crossing the study area in the East (Fig. 1) had ECdw lower than those estimated by the model due to dilution by canal seepage waters (canal EC of about 0.4 dS m^{-1}). The deletion of these outliers from the regression increased its coefficient of determination by 30% (R2 = 0.73). We therefore concluded that the ECa mapping of the study area is a sensible approach for delineating the salinity-source areas provoking the salinity of drainage waters.

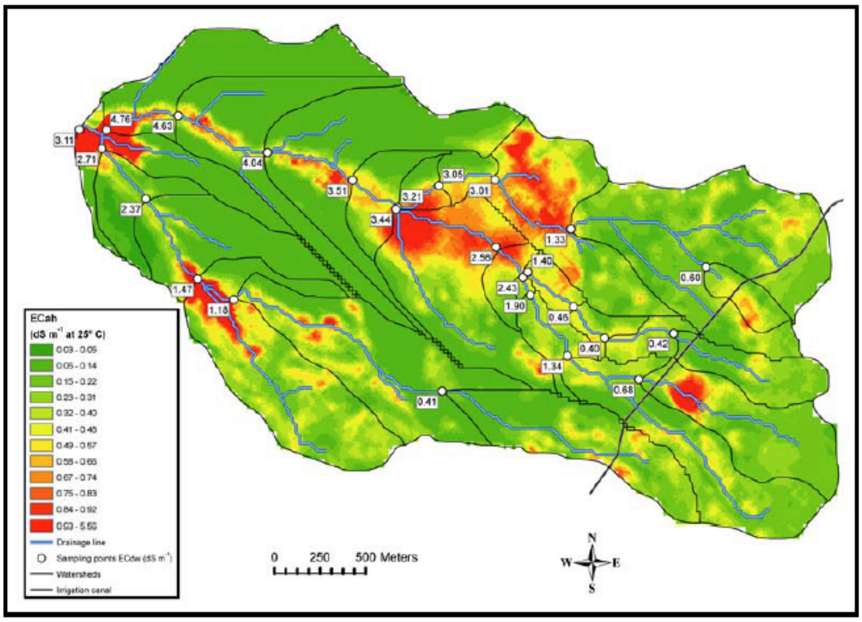

Figure 1 **Raster map of apparent soil electrical conductivity (ECah) in the Barranco de Lerma study area. The delineation of the 25 watersheds within this area and the EC of the drainage waters (ECdw) at the exit of each watershed are also shown.**

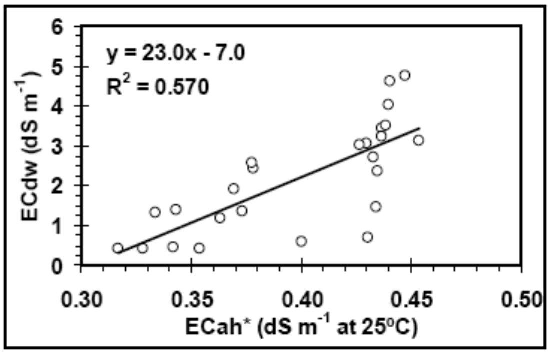

Figure 2 **Linear regression between drainage water salinity (ECdw) and surface-weighted apparent soil electrical conductivity (ECah*) for the 25 watersheds delimited in the Barranco de Lerma study area.**

Waters

The quality of rivers in the ERB was evaluated in terms of the geochemistry, salt loads, salinity tendencies and suitability for irrigation using the databases of the Ebro River basin Authority (CHE).

The average EC for the 31 river stations with available information for the last 30 years is 0.88 dS m^{-1} (C.V. = 58%; minimum = 0.23, maximum = 2.4), with an EC of 1.0 dS m^{-1} for the Ebro River close to its outlet in the Mediterranean sea. Salinity increases towards the middle of the ERB due to natural (saline geologic materials) and man-made (irrigation return flows) salinity sources (Isidoro and Aragüés, 2007).

River water quality in the ERB is generally good in regards to salinity, main ions (dominated by Ca and SO_4 due to the presence of calcite and gypsum minerals in the basin), NO_3 and PO_4. Thus, leaching requirements are very low (lower than 10% for 90% of the irrigation waters) and, therefore, high irrigation efficiencies are attainable without compromising crop yields due to root zone soil salinization. In contrast, low EC waters may degrade the structural stability of sensitive soils. Thus, the EC-SAR values of 80 river stations plotted on the FAO water quality guidelines for irrigation (Ayers and Westcot, 1985) indicate slight to moderate soil infiltration problems in most of the large irrigation schemes located in the left margin of the Ebro River (Fig. 3). An automatic infiltrometer was developed to further evaluate the relative responses of the steady-state infiltration rate (IR) in soils subject to gypsum-saturated, irrigation canal and deionized waters. Based on the gypsumsaturated IR, the decreases in IR of soils subject to canal water and rainfall (deionized water) properly quantified the sensitivity of these soils to losses in structural stability.

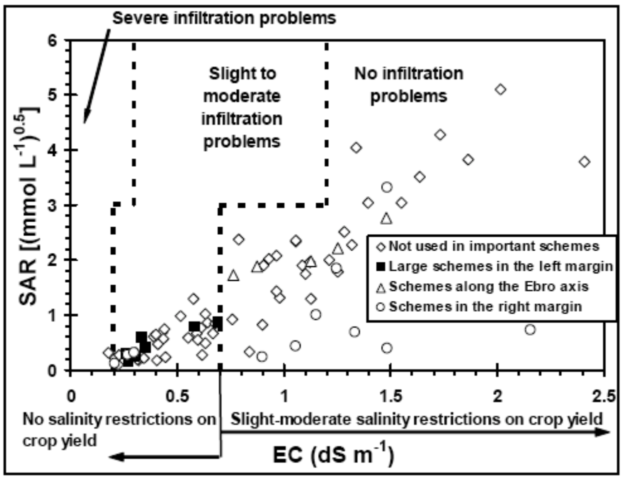

Figure 3 Mean 1988-1990 EC-SAR values of 80 river stations of the ERB plotted on the FAO water quality guidelines for irrigation Crops

We analyzed the foliar absorption of salts under saline sprinkler irrigations, its effect on crop yields and the minimization of salt damage using two recommended management strategies: (a) short preand post- freshwater sprinkler applications and (b) nocturnal vs. diurnal saline sprinkler irrigations. The hypothesis for (a) is that injury caused by saline sprinklings could be reduced by applying fresh waters at the beginning and the end of each irrigation in order to decrease salt absorption through leaves. The hypothesis for (b) is that because of lower temperature, solar radiation, wind speed and higher relative humidity, irrigating at night would reduce the concentration of ions absorbed by the leaves and its potential deleterious effects on crop yields.

(a) Effect of short pre- and post-fresh water sprinkling irrigations in barley sprinkler irrigated with saline waters

Barley grown in pots outdoors was sprinkler irrigated with saline water (9.6 dS m^{-1} with 47 mmol L^{-1} NaCl) two to three times per week for a total of 28 irrigations (Benes et al., 1996). The two sprinkler treatments were (1) saline soil and saline sprinkling with 5 min pre-wetting and 5 min post-washing with fresh water (EC = 0.6 dS m^{-1}), and (2) saline soil and saline sprinkling without pre-wetting and post-washing. For comparison purposes, an additional treatment consisted in a non sprinkled, saline soil drip-irrigated with the 9.6 dS m^{-1} solution (Table 2).

Table 2 Effect of pre-wetting and post-washing with fresh water on leaf sap Cl and Na concentrations (mmol L^{-1}, averaged over five sampling dates ± s.e.) and on grain yield of barley grown in saline soil and sprinkler-irrigated with saline water. Results for saline soil, non-sprinkled plants are also shown

Treatment	Leaf Cl	Leaf Na	Grain yield
Saline soil, sprinkled			
no pre-, no post-	411 ± 9	212 ± 10	61 ± 6
pre- and post-	271 ± 5	135 ± 5	121 ± 4
Saline soil, non-sprinkled	251 ± 6	93 ± 4	145 ± 7

When pre-wetting and post-washing were applied, leaf Cl and Na were significantly lower than those in plants sprinkler irrigated without pre-wetting and post-washing (Table 2). In agreement with these concentrations, the pre-wetting and post-washing yield was two times higher than the yield without pre-wetting and post-washing. Moreover, the yield obtained in the pre-wetting and post-washing saline soil was reduced only by 17% of that in saline soil, non-sprinkled plants (Table 2). In conclusion, where waters of good and poor quality are available, short pre-wettings and post-washings with fresh water would permit the use of saline waters that otherwise will not be suitable for irrigation.

(b) Effect of nocturnal vs. diurnal saline sprinkling irrigations in alfalfa

One to three 1.5-h nocturnal and diurnal saline sprinkler irrigations were given weekly to alfalfa from May to October using a Triple Line Source system (Aragüés et al., 1992) where the two laterals diverted saline water (EC = 5 dS m^{-1}, SAR = 16) and the central line fresh water (EC = 0.4 dS m^{-1}).

Table 3 shows that leaf Cl and Na concentrations increased with increasing ECiw, but yields remained unaffected. Leaf Cl and Na were somewhat lower for the nocturnal than the diurnal sprinkler irrigations given with the 3.1 and 4.3 dS m^{-1} waters, but the yields were not significantly different. The recommended practice of irrigating at night when using sprinkling saline waters was not therefore supported by our results in alfalfa. A similar conclusion was obtained in corn (data not given).

Table 3 Effect of diurnal and nocturnal sprinkling irrigations with waters of three salinities (ECiw) on leaf Cl and Na concentrations (% dw averaged over three sampling dates) and on dry hay yield (Mg ha^{-1}) of alfalfa

Treatment	ECiw = 1.0 dS m^{-1}			ECiw = 3.1 dS m^{-1}			ECiw = 4.3 dS m^{-1}		
	Cl	Na	Yield	Cl	Na	Yield	Cl	Na	Yield
Diurnal	1.71	0.45	20.5	2.66	0.99	18.8	2.68	1.15	20.6
Nocturnal	1.70	0.48	22.5	2.22	0.83	19.3	2.62	1.09	18.4

Acknowledgments

Projects financially supported by the European Commission, the Spanish Ministry of Education and Science, and the Ebro River Basin Authority (CHE).

References

Aragüés R., Royo A., Faci J., 1992. Evaluation of a triple line source sprinkler system for salinity crop production studies. Soil Sci. Soc. Am. J. 56: 377-383.

Ayers R.S., Westcot D.W., 1985. Water quality for irrigation. FAO irrigation and Drainage Paper 29, Rev. 1, Rome. 174 pp.

Benes S.E., Aragüés R., Austin R.B., Grattan S.R. 1996. {PRIVATE }Brief pre- and post-irrigation sprinkling with freshwater reduces foliar salt uptake in maize and barley sprinkler irrigated with saline water. Plant and Soil 180: 87-95. {PRIVATE }

Isidoro D., Aragüés R., 2007. River water quality and irrigated agriculture in the Ebro River basin : an overview. Int. J. Water Res. Devel. 2: 91-106.

Rhoades J. D., Chanduvi F., Lesch S., 1999. Soil salinity assessment: Methods and interpretation of electrical conductivity measurements. FAO Irrigation and Drainage Paper 57. Food and Agriculture Organization of the United Nations, Rome, Italy, 150 pp.

Urdanoz V., Amezketa E., Clavería I., Ochoa V., Aragu□.s R, 2008. Description of a mobile, georeferenced electromagnetic sensor and soil salinity appraisal applications. Spanish J. Agric. Res. (submitted).